ACCURACY IN MACHINE TOOLS: HOW TO MEASURE AND MAINTAIN IT.*

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THE final inspection and testing of a new machine tool in the maker's works is carried out by experienced fitters and inspectors, who have usually been engaged in the various stages of erection and are familiar with every part of the machine. Intimate knowledge of the machine and of the correct use of measuring instruments and finishing tools enable them to assemble the machine in such a way that errors in individual components, within their respective admissible tolerances, have a negligible effect upon the working accuracy of the machine as a whole.

In addition, the user sends a representative who is capable of conducting the acceptance tests of a machine. He knows which limits must be rigidly adhered to, and which may in debatable cases be relaxed so long as the machine produces workpieces within the required limits of accuracy.

Disagreement between makers and users regarding the correct limits of accuracy of machine tools are readily overcome by the use of "Acceptance Test Charts."† These charts are a means whereby the maker and user can work together without friction.

The Acceptance Charts are also useful for checking machines in use and for the inspection of machines after repair.

To-day the machine tool user expects to produce parts which conform to B.S.I. limits on machines operated by ordinary experienced workmen. There must be no necessity for special professional skill to "off-set" faulty machines. For this reason inaccuracies due to the wear of the machine must not exceed certain limits. The machine must be watched and worn or damaged parts replaced or repaired immediately.

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* Reprints of this report bound in cover, suitable for shop use be can obtained on application to the Institution.

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† c.f. "Acceptance Test Charts for Machine Tools" published jointly by the Institutions of Mechanical and Production Engineers, London, March, 1940.

Effective maintenance and *prompt repair* are essential to steady production. They act as preventatives, eliminating those long and costly delays which inevitably occur when an important machine tool breaks down. Emergency repairs will, indeed, always be unavoidable ; precautions should be taken to avoid their repetition.

Maintenance of the machine includes—

(1) Checking the accuracy of the finished workpieces.
(2) The preparation and, if necessary, the assembly of the parts required for replacements.
(3) Estimating the costs of the various items of the repair.
(4) Directions to production foremen and workmen regarding the correct use of machine tools.
(5) Repair or rebuilding of the whole machine.
(6) Emergency repairs.

Errors in workpieces may appear after a certain time, as a result of natural wear of machine parts. This, if noticed in time, can be prevented either by using the existing adjusting mechanism or by some small correction done after working hours. After a long period of work, or if overworked, the machine must undergo a reasonable overhaul, preferably in accordance with a certain time plan.

The repair can either be restricted to replacing the worn-out or damaged parts or surfaces, or can be extended to include the modernisation of the entire machine by *rebuilding*. To be effective, rebuilding must be supervised by a machine tool expert, who is capable of meeting the increased demands of our times, by the inclusion of new bearings, hardened and ground spindles, new gears, better lubrication, facilities for the introduction of coolant, etc.

We shall now consider the people who carry out the repair and the methods used.

The manager of the repair shop should be responsible to the chief engineer and should have full power to maintain in good condition all machines used in the factory. The foremen and workmen must be carefully selected and instructed on the type of work they have to carry out. They must not only be able to work in accordance with fine tolerances, but must also be sensible to faults in construction and know how to remove them. This must not be a department in which worn-out workmen are deposited.

In small workshops the inspection and repair are generally done by the same man. In big shops a special inspector works side by side with the workman who is carrying out the repairs. In order to carry out the work, the only measuring instruments required are those already in general use for machine tool inspection. Of course, other tools are wanted for scraping, checking and measuring, as

well as the special equipment which will be adapted to the particular demands of each machine.

Besides the regular periodic inspection of the machines, they must be inspected as soon as they produce workpieces which do not conform to the required limits of accuracy. Only when the reasons for such faults are known can they be remedied.

Before the workman re-examines the machine he must have precise instructions regarding the following:

(1) The correct *shape*, *position* and *direction of motion* of those parts of the machine tool which affect the accuracy of the workpieces produced on the machine. In the case of the lathe, for example, the *shape* of the spindle is very important—it must be true*[1]. The position of the tailstock relative to the headstock is important. Their axes must be in line*[2]. The *direction of motion* of the carriage must be parallel to the spindle*[3].

(2) The best methods of conducting the tests and how to use the tools and instruments required for testing.

The requirements of (1) are fulfilled by the "Acceptance Test Charts." Each chart contains limits of error permissible in the shape, position and direction of motion of those parts of the machine which affect the working accuracy. In addition, the permissible tolerances of the workpiece are given in the practical tests at the end of each chart. These tolerances conform to the B.S.I. fits and limits.

The requirement of (2) are supplied by this booklet, which gives full instructions regarding the use of the measuring instruments concerned, and details of the methods of conducting the tests.

The test charts relating to any class of machine such as lathes, milling machines, etc., give the general structure together with the tolerances to which the various units, such as spindles, cross slide, etc., must conform.

The general method of procedure followed in the charts is as follows:

(1) The machine is set up and the principal horizontal and vertical planes and axes are checked with a spirit level.

(2) The straightness, parallelism and quality of the guiding and bearing surfaces of beds, uprights and base plates are tested.

(3) The main spindle, as the fundamental element of the machine, is tested for concentricity (true running), axial slip, accuracy of axis, and position, relative to other axes and surfaces.

(4) The movements of all the working components are then checked.

Acceptance Test Charts of I.M.E. & I.P.E.:
* (1) Lathe test 7.
* (2) Lathe test 18.
* (3) Lathe test 10.

(5) *Working tests* are conducted to determine whether the machine, as a whole, produces finished workpieces within the specified limits of accuracy.

This general scheme is applicable to all machines so that it is only necessary in this booklet to give detailed explanations of tests on a few machines in most general use. The examples selected refer to *lathes*, *milling machines*, *cylindrical grinding machines* and *radial drilling machines*.

The machine tool maker of to-day frequently confines himself to the manufacture of certain classes of machine tools, perhaps even to a single class, such as lathes or milling machines. Nevertheless he is himself a user of many types of machine tools. The quality and accuracy of the machine tools, which he makes, are directly dependent upon the quality and accuracy of the machine tools which he uses. Effective maintenance and repair are, therefore, of the highest technical and economical importance. The " Test Charts " are the best guide to effective maintenance.

Machine tool repairers do not generally specialise, as do machine tool manufacturers. On the contrary, many repair shops deal with a wide variety of machines. Under such conditions it is essential to have to hand standards of control and acceptance based on long and specialised experience with each individual class of machine tool.

Sequence of Acceptance Tests.

(A) *Accuracy of the Machine Tool itself*:

I. Erecting and setting up.
II. Testing guidances and movements.
III. Testing the main spindle and its relation to other important units and components.

(B) *Accuracy of the Finished Workpieces.*

(C) *Power Consumption.*

First the general methods used in the inspections A, B and C are described, then follows an outline of the application of these methods to the lathe, milling machine, grinding machine and radial drill.

A.I. Erecting and Setting Up the Machine.

Surfaces may be checked with reference to the horizontal plane by use of a *spirit level* as a very simple and accurate instrument. Starting from this base feeler instruments can be used for both horizontal and inclined planes (c.f. Fig. 35).

The alternative method of using the surface of a liquid is shown in Figs. 1 and 2. When the surface of the way is to be tested directly an arrangement such as the bridge piece " a," shown in

Fig. 1, is made to carry a measuring point over the surface of the liquid, which is contained in any convenient channel, in this case a vee-way of the machine, the ends of which are sealed with clay. When the movement of a table or slide on its way is to be checked, an arrangement similar to that shown in Fig. 2 is most convenient. The illustration shows how the movement of the table of a planing machine is checked by mounting on each side measuring points lengthwise *a*, *a*, crosswise *b*, *b*, which move over the surface of a liquid contained in a length of channel iron, the ends of which may be sealed by clay. To ensure that both measuring points are referred to the same horizontal plane, a communicating pipe should connect the two channels of liquid.

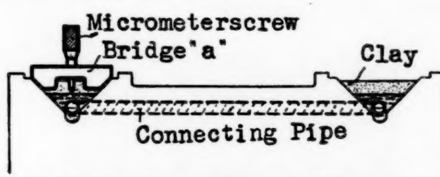


Fig. 1.—Surface of liquid and measuring point. Using vees of bed as water channels when erecting machine.

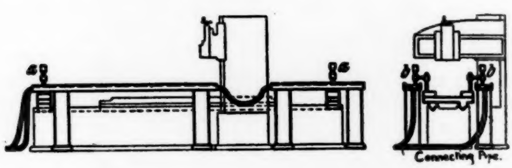


Fig. 2.—Checking the movement of a planing machine using two lengths of channel iron as liquid container. Measuring points aa lengthwise, bb crosswise.

In the case of very long beds, deviations in the horizontal plane can be detected by a taut wire and microscope (Figs. 3 and 4). The alignment telescope and collimator (Fig. 5) or the telescope

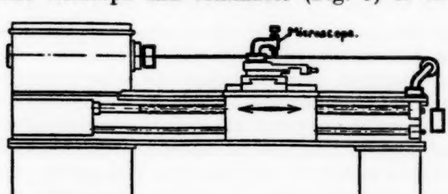


Fig. 3.—Lathe aligned by taut wire.

and target (Fig. 6) can be used to check deviations of long beds in horizontal, vertical or inclined planes.*

Method of Testing by Means of Wire and Microscope.

The wire method (Fig. 4) serves for measuring the straightness of movements of tables and carriages over greater lengths. The two ends of the wire are lined up by means of the cross wires of the measuring microscope. Observations are taken in the vertical plane as the table is traversed. By means of a special system of prisms, however, the wire can be observed both vertically and horizontally. Each vertical and lateral deviation may be measured by the displacement of the microscope tube. The amount of sag of the wire can be accurately calculated.

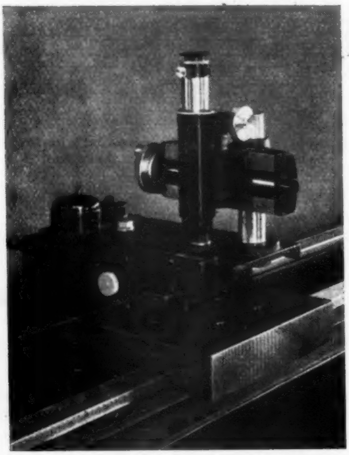


Fig. 4.—Method of testing horizontally and vertically by means of a taut wire and microscope.

In the case of a lathe or grinding machine, the wire should be so secured that it is exactly co-axial with the centres.

Care must be taken, however, that the wire is free from angles or kinks. The thickness of wire should be as small as possible, the maximum thickness being 0.004 in. Long beds up to 65 ft. and more can be tested without the need for special precautions. For greater lengths it may be necessary to damp the vibrations of the wire by suitable means, for example, by attaching small paper banners which are arranged to dip into oil.

Alignment Test by Telescope and Target.

The weak points of the method of alignment testing with the taut wire are avoided if the optical axis of a telescope is used as the rectilineal reference, a suitable mark which slides on a carriage on the bed being observed through the eyepiece. When using the telescope and collimator, Fig. 5, the sight mark of the telescope is observed simultaneously with the image of the target formed by the collimator (apparently at infinity). In this way the variations in the angle between the axes of the collimator and the telescope are determined. The method is similar to that utilizing a spirit level.*

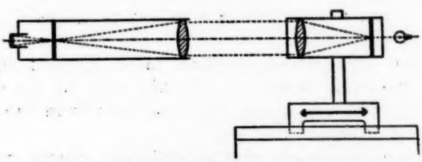


Fig. 5.—Measuring telescope and collimator.

With the telescope and target method, however, the vertical or lateral deviations are measured directly in inches as the target is moved between its extreme positions E and F (Fig. 6).

Because the telescope forms a real image by convergent rays, it is necessary to focus the telescope very accurately every time, according to the distance of the target. Focusing is carried out with the aid of a movable lens within the telescope, actuated by the knob K. The displacement of the lens must be so accurately

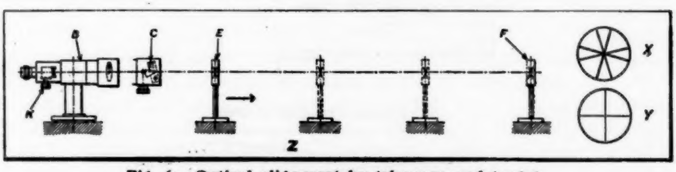


Fig. 6.—Optical alignment by telescope and target.

rectilineal that there are no sensible deviations in measuring. The results of the test give, at the same time, errors of alignment in both the vertical and horizontal planes of the optical axis. The plane-parallel plate C permits the adjustment of the optical axis of the telescope relative to the mark when taking readings. The accuracy of the test depends on the magnification of the telescope, the smallness of the divisions and the magnitude of the distance

* cf. Journal of the I.P.E. Vol. XIX, No. 9, 1940, p. 317. Modern Measuring Instruments.

between the telescope and the mark. The accuracy of the result also depends upon the movement of the focusing lens and of the plane parallel plate which can be made very accurate. The minimum distance of the mark from the telescope is about 42 in. Another method of testing a movement for straightness is by means of a

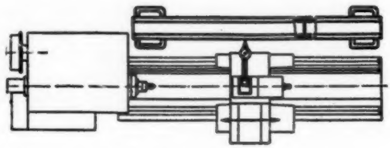


Fig. 7.—Long straight-edge and dial gauge.

long, horizontal straight-edge which is so aligned that the dial gauge shows the same deflection at both ends of the edge, Fig. 7. While the table is moved along, the deviation from the straight line may be read off from the dial gauge.

The tolerances given in the acceptance charts represent the permissible deviations from perfectly straight lines, or absolutely plane surfaces. Deviations are permitted in any direction perpendicular (Fig. 8) to the plane or line of reference, unless the test chart specifies a particular direction, e.g., tolerance = 0.00025 in/ft. surface convex only (Fig. 9).

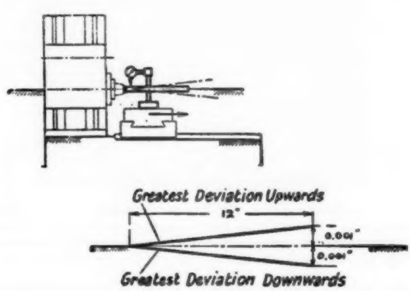


Fig. 8.—Bilateral tolerances.

Spirit levels are used almost exclusively in the ordinary workshop and are in the shape of a vial mounted in a cast-iron base. The two main kinds are the horizontal (Fig. 10) and the frame spirit level (Fig. 11). Their sensitivity must be adapted to the grade of precision of the machine tool. It is given by the value of one scale division.

For machine tools, spirit levels having scale divisions between 0.0004 in. and 0.0006 in. per ft. (=0.03 to 0.05 mm. per one meter) are in use. One division movement of the bubble corresponds to a change of 6 to 12 seconds in the inclination of the level to the horizontal.

It is advisable to choose a level of 0.0005 in. per ft. (0.04 mm. per one meter). The distance from division to division ought not to be smaller than 0.1 in.

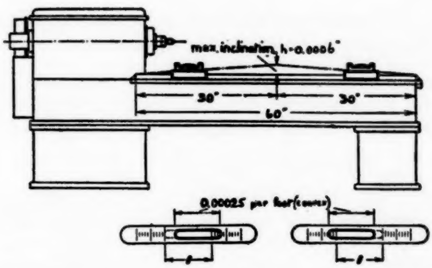


Fig. 9.—Unilateral tolerances used to specify convexity of front way of lathe.

It is quite easy to estimate to within a quarter of a division, and agreement regarding such estimation can easily be arranged between the inspectors of both maker and client.

The errors of the spirit level are caused by: (*a*) Wrong position of the glass tube in the case. (*b*) Faulty division of the tube. Deviations depend on the quality of the base and its length (not smaller than 8 in. (200 mm.), better 10 in. (250 mm.) to 14 in. (350 mm.) (*c*) variation in the shape of the case; (*d*) the accuracy of the inside of the vial, which must have uniform curvature to make certain that each division indicates the same angle of inclination.

Errors and deviations should be smaller than a quarter of a division; then one can practically ignore them. Unfortunately errors and deviations often reach half a division with workshop levels. Errors which may arise through incorrect use of the spirit level are caused by—(*a*) condition of the piece to be tested; (*b*) influence of temperature; (*c*) personal errors of the inspector.

(*a*) If the surface to be tested is geometrically inaccurate, the base of the level may not lie parallel to it. The bubble indicates the position of the base of the spirit level. If this base is not parallel to the surface to be checked, the indication of the bubble is misleading. The indication of the bubble refers only to the straight line in the direction of measuring (lengthwise). Therefore the level must always be set up in different measuring

directions, if *planes* are to be checked. It is advisable to check the character of the surface by some other method such as straight-edges, surface plates, autocollimator, slip gauges, etc.

(*b*) The tests should be conducted at a temperature of 68°F. (20°C.). Deviations caused by sunbeams, draughts of air, breathing, touch by warm hands, etc., lead to faulty indications. Breathing on and touching the bubble vial should be carefully avoided. A transparent protecting cover (mica) is desirable.

(*c*) It is best to take readings with both eyes open and looking in a direction perpendicular to the bubble vial.

The inspector must always keep to the same method of observation, *e.g.*, he must always use one eye or always use both. The level must not be used on its edge, but should always be properly

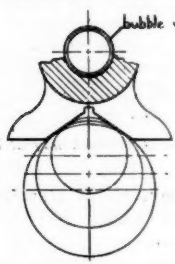


Fig. 10.—Spirit level and checking cylinders.

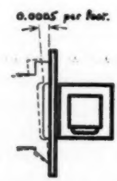


Fig. 11.—Frame level on vertical surface. (On straight-edge).

pressed to the surface under inspection. Using a cross or circular level facilitates correct measuring, especially in adjusting inclined surfaces. In other cases the measuring direction must be adjusted by trial and error.

Monthly testing of the spirit level used in the shop is recommended, and when necessary adjustments should be made. The surface of the base of the level should always be treated with care.

Checking the level includes the following items: (1) Parallelism of the measuring surfaces of the base; (2) correct position of the base surfaces in relation to the bubble tube of the level; (3) accuracy of the scale divisions (sensitiveness).

(1) Parallelism is tested by red lead and deviations are corrected.

(2) The testing is done in the test room when frame and checking device have reached the same temperature, (20°C.=68°F.). This will certainly be the case after eight hours (overnight). The shape of the base surface is important. With a full surface

the right position of the vial is tested by turning through 180°. If the surface to be tested is horizontal, the bubble must be adjusted within $\pm$ 0.25 of a scale division. With a V-shaped base very accurate hardened steel cylinders of different diameter are required for checking (Fig. 10). The base can be retouched to make the sides of the V parallel. In checking the longitudinal inclination of the vee to the bubble vial care should be taken that the cross level reads zero during each observation.

In the case of frame spirit levels (Fig. 11) it is necessary, in addition to the above-mentioned tests, to ensure that all the measuring surfaces of the level are perpendicular or parallel to one another. This can be done by use of accurate squares.

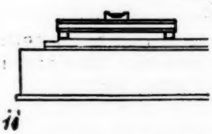


Fig. 12.—Level on bridge.

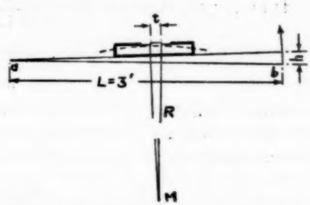


Fig. 13.—Sensitiveness of spirit level.

The usual tolerance of the level itself is half a division. The bearing length of the spirit level should be as large as possible; it should be at least 8 in., *without interruptions* in the base, which are frequently very disturbing. A good method is to use a bridge (Fig. 12), the feet of which are about 12 in. apart, and to place the spirit level on the well-scraped surface at the bridge.

To check the scale divisions an accurate straightedge is set to heights a and b by slip gauges and knife edges, 3 ft. apart (Fig. 13). Suppose the spirit level to be checked is graduated to read 0.0005 in. per foot for each division. The straightedge must be set horizontal by using an accurate level, which is kept specially for calibration purposes. One end support should then be changed so that there is a difference in height of 0.0015 in. between the two points=3 ft. apart. The bubble should then have moved one division towards the higher end. In the same way the whole scale can be checked division by division.

The *sensitiveness* of the spirit level is the movement of the bubble in inches, corresponding to an inclination of the whole level of 0.012 in. per ft. (1 mm. per 1,000 mm.).

$$\text{Sensitiveness} = E = \frac{\text{Movement of bubble in inches}}{\text{in. per ft.}}$$

If the length of one division on the bubble holder is t inches and one division (t inches) movement of the bubble corresponds to a change of the inclination of the level of S inches per foot, then

$$E=\frac{t\text{ ins.}}{S\text{ ins. per foot}}$$

i.e., change of inclination of the level corresponding to one division movement of the bubble

$$=S=\frac{t\text{ in./ft.}}{E}$$

e.g., if the length of a scale division is t=0.1 in., and this movement of the bubble corresponds to a change of inclination of 0.0005 in. per foot, then sensitiveness $=E=\dfrac{0.1\text{ in.}}{0.0005\text{ in./ft}}$.

$$=\frac{200\text{ in.}}{\text{in. per ft.}}$$

In a similar manner, if the sensitiveness E and the length of a division t are known to be 200 and 0.1 respectively, then the inclination S corresponding to a scale division is given by

$$S=\frac{t\text{ in.}}{E\text{ ft.}}$$

$$=\frac{0.1\text{ in.}}{200\text{ ft.}}$$

$$=0.0005\text{ in. per ft.}$$

The inside of the glass tube of a spirit level is in the form of a circular arc. Let this arc have radius R and centre M (Fig. 12). If the inclination of the spirit level is altered, the bubble moves around this arc. From Fig. 12 it is clear that

$$\frac{t}{R}=\frac{h}{L}$$

$$\text{thus} R=\frac{t}{\text{h/L}}$$

But $\dfrac{t}{\text{h/L}}$ = sensitiveness E.

Therefore radius of inside surface of vial = sensitiveness.

$$R=E.$$

Consequently the sensitiveness depends only on the radius of curvature of the inside surface of the vial and not on the length of the base of the level. A short, accurate level may be more sensitive than a coarse, long one (mason's level).

If a spirit level has scale divisions 0.1 in. long, which represent changes in inclination of 0.0005 in. per foot, then

$$\text{Radius of inner surface of vial} = R = \frac{t}{h/L} = \frac{0.1}{0.0005}$$

$$= 200 \text{ ft.}$$

In order to reduce $\frac{h}{L}$ to 0.00025 in. per ft., the radius must be increased to 400 ft. Spirit levels with greater radii than from 150 to 200 ft. are very difficult to use in workshops. These (astronomic) levels never come to rest in ordinary workshops. It is usual to use spirit levels with scale divisions of 0.0005 in. per ft. (0.04 mm/m.) for the adjustment of—

I. Lathe beds (Fig. 33).
II. Tables of the milling machines (Fig. 44).
III. Beds of the grinding machines (Fig. 55).
IV. Base plate and columns of the radial drill (Figs. 68 to 70).

A.II. Testing the Quality of Guiding and Bearing Surfaces.

Although uniform standards have not yet been established for the surface finish of machine ways, measurements for the flatness, straightness and parallelism of these ways, have been successfully introduced. A useful method of checking scraped or ground surfaces is to pass the feeler of a 0.0001 in. dial gauge over them. The dial gauge stand should have a large base which should be mounted on a well-scraped or ground plane of comparison. For this purpose the point of the hardened feeler must be about 0.04 in. radius. No points on the surface should be more than 0.0001 in. to 0.0002 in. below the real bearing spots. The feeler of the dial gauge should be moved in several parallel lines along the surface to be tested. This will quickly reveal the evil effects of mottling which should not be required on a properly scraped surface (c.f., Fig. 34).

A.III. Testing the Workspindle in Relation to other important Units.

In general, checking the work-spindle includes investigations of—

(1) True running of
   (*a*) the centre,
   (*b*) the internal taper,
   (*c*) a centring cylinder of an external taper, etc.,
(2) Axial slip,
(3) Alignment,
(4) The parallelism of the work-spindle to the guide ways,
(5) Perpendicularity of work spindle to guide ways.

1. True Running.

True running of spindles can be checked by use of the dial gauge as shown in Figs. 15 to 18.

The total error revealed by applying the dial gauge to a rotating mandrel as shown in Fig. 14*a* includes three main sources of error. They are—

(i) Inclination of axis of mandrel to axis of rotation. Angle α (Fig. 14*b*).

(ii) Eccentricity of axis of mandrel with respect to axis of rotation, distance " e " (Fig. 14*b*).

(iii) Lack of roundness of surface tested, as shown in enlarged cross-section, XX, Fig. 14*b*.

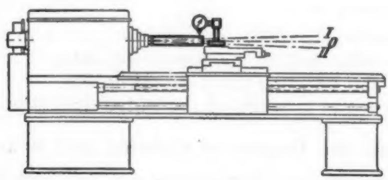


Fig. 14a.—Mandrel running out of truth must be set to mean position (0) before testing for parallelism with bed.

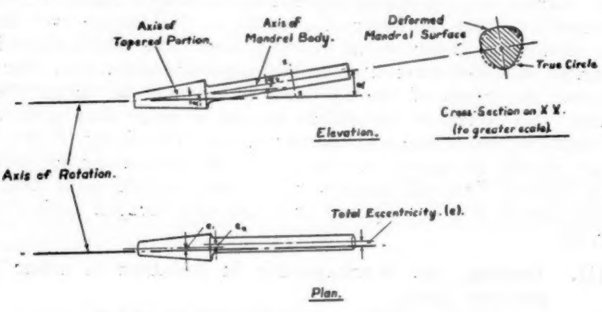


Fig. 14b.—Sources of errors of rotating mandrels.

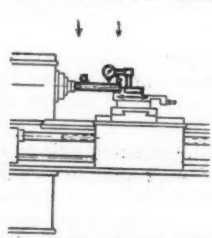
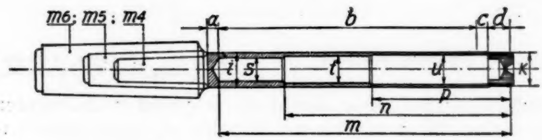


Fig. 19.—Taper shanked cylindrical mandrel—(a) near spindle nose (b) in 12 in. distance.

A dial gauge calibrated in 0.001 in., 0.0005 in., or 0.0001 in. per division should be used for this test. The calibration of the dial gauge should be checked every three months with accurate slip gauges.

The tolerance given for running true refers to the permissible movement of the dial gauge pointer during one complete revolution of the machine spindle. The errors recorded are dependent on the axial distance of the dial gauge feeler from the spindle nose, and this distance should be clearly stated in the test results. The measurements should always be made at two points, near the spindle nose a and at the end of the mandrel b.



Morse taper No.		External Cylinder (in.)						Bore (in.)						Total lgth.
		Length				O'side ϕ		Depth			ϕ of bore			
		a	*b*	*c*	*d*	*i*	*h*	*m*	*p*	*s*	*s*	*t*	*u*	*L*
1	2	$\frac{5}{16}$	4	$\frac{5}{16}$	$\frac{3}{4}$	$\frac{5}{8}$	i-0.4	—	—	—	—	—	—	$5\frac{1}{8}$
3	4	$\frac{5}{16}$	8	$\frac{5}{16}$	$\frac{3}{4}$	1	i-0.4	—	9	6	—	$\frac{1}{2}$	$\frac{3}{4}$	$9\frac{1}{8}$
5	6	$\frac{3}{8}$	12	$\frac{3}{8}$	1	$1\frac{5}{8}$	i-0.4	$13\frac{1}{2}$	10	$6\frac{1}{2}$	$\frac{3}{4}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$13\frac{3}{4}$
6	—	$\frac{5}{8}$	20	$\frac{5}{8}$	$1\frac{5}{16}$	$2\frac{1}{2}$	i-0.4	$21\frac{1}{2}$	16	10	$1\frac{1}{2}$	$1\frac{7}{8}$	2	$21\frac{13}{16}$

Fig. 20.—Hollow test mandrels and table of dimensions.

(1a, b). Usually the tests for true running of centre points are only necessary on lathes and grinding machines, whereas tests for true running of internal taper using a taper shanked mandrel are necessary on most machines which have a rotating spindle, e.g. lathes, grinding machines, milling machines, drilling machines, etc.

The method of making this measurement is shown in Fig. 19. The mandrel, which should have a cylindrical portion 12 in. long, should be placed in the spindle taper. With the feeler of the dial gauge resting on the cylindrical surface of the test mandrel, the deviation is read, as the spindle is slowly rotated. Observations are taken at *a*, near the spindle nose, and at *b*, 12 in. from the spindle. To eliminate the influence of natural sag which must be taken into consideration, it is advisable to make the test mandrels hollow, and to provide them with a taper shank, the large diameter of which is greater than the measuring cylinder. Fig. 20.

The measuring length of the mandrels depends on the manner of use, and amounts from 12 in. to 4 in. in the case of taper shanked mandrels. The diameter must be so chosen that the amount of sag or deflection caused by the deadweight will be negligible. The deflection caused under the measuring pressure of a dial gauge (three to four oz.) is of no account.

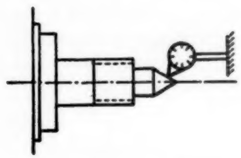


Fig. 15.—Checking of centre.

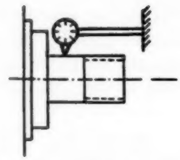


Fig. 16.—Checking cylinder of threaded spindle nose.

The female centre cones should be provided with countersunk recesses so that the mandrels are capable of being always tested for true running.

Before applying any directional measurements, the working spindles should be tested for out of truth running by means of an inserted test mandrel. The spindles should next be set to the mean position of the eccentricity error, thus eliminating its influence on the measuring results. In the mean position the required measurements may be accomplished.

Example : Lathe spindle parallel with bed in the vertical plane (spindle rising towards the free end of mandrel only). The tolerance is 0 to 0.0008 in. measured on a length of 12 in.

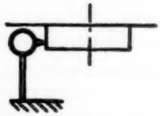


Fig. 17.—Checking of cylinder (spigot).

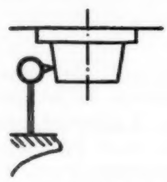


Fig. 18.—Checking of external taper.

Before taking the measurement let it be determined that the spindle is out of truth or off-centre between the two directions I and II, as measured at the end of the mandrel (Fig. 14*a*). The spindle is so rotated that the dial gauge is in the position 0, i.e. in the mean position between I and II. Measuring of the parallelism between spindle and bed can now be carried out.

(1c). External centring devices—cylinder (Fig. 16 and 17), taper (Fig. 18) for the various chucks, face plates, etc., are tested in a

similar way. The dial gauge is put on the circumference of the centring surface, the spindle is slowly turned, and the maximum error indicated by the clock is read.

(2) *Axial slip*. When testing the axial slip of a spindle, the feeler of the dial gauge rests on the face of the locating spindle shoulder. The total error indicated by the movement of the pointer includes three main sources of error. (Fig. 21).

(i) Axial slip due to error in the bearings *a*.
(ii) Face of the locating shoulder not in plane, perpendicular to axis of rotation *b*.
(iii) Irregularities of front face *c*.

The total error indicated by the dial gauge is $a + b + c$. Errors a and b are usually large compared with c.

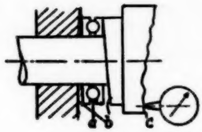


Fig. 21.—Axial slip-errors.

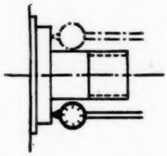


Fig. 22. —Face of shoulder to be tested at two opposite positions.

If the feeler touches at the same spot as that, at which the turning tool or the emery wheel has machined the spindle collar in the assembled machine, the feeler would not show any deviation. Therefore, the axial error must always be tested at two points 180° apart, on the collar of the working spindle. (Fig. 22).

The feeler of the dial gauge should be applied to the front face of the work-spindle, which is turned slowly under a constant end thrust, acting along the axis of the spindle against the thrust bearing. The deflection of the pointer must be observed and the test repeated with the feeler in two positions diametrically opposite on the spindle.

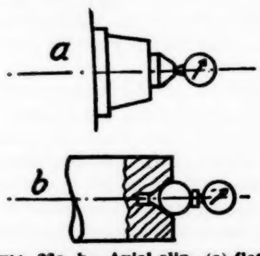


Fig. 23a, b.—Axial slip—(a) flattened point (b) ball in centre bearing.

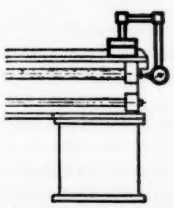


Fig. 24.—Axial slip of lead screw.

The effect of obliquity and uneveness of the front face must be eliminated if the axial slip is to be determined. This is done by arranging the line of movement of the feeler to coincide with the axis of the spindle. The feeler may be made to rest directly on a surface perpendicular to the axis of rotation or on a ball placed in a hole central with the spindle.

Examples of the application of this are shown in Figs. 23a and b. When the spindle is rotated during this test, it should be subject to a constant axial force acting toward the bearing which takes up the end thrust. In the case of a lead screw, the axial force can be in either direction, but must not be changed (Fig. 24), with central ball (Fig. 23*a*).

(3) *Alignment.* The permissible deviation of the axis is stated in the alignment test. It is necessary to describe the precise position along the axis of those surfaces, the alignment of which is to be checked. In some special cases it is necessary to describe the plane in which the alignment error is permissible.

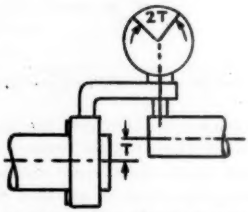


Fig. 25.—Turnround reading.

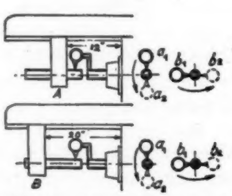


Fig. 26a, b.—a/b Trammel reading—overarm of milling machine.

If the alignment is checked by running a dial gauge about an axis so that the feeler describes a cylinder around the surface to be checked (Fig. 25), the movement of the dial gauge pointer is twice the actual eccentricity of the cylinder relative to the axis about which the dial gauge is swung. For this reason, the permissible deflection of the dial gauge pointer is twice the tolerance given in the test charts. An eccentricity T, as shown in Fig. 25, produces a deflection 2T of the dial gauge pointer.

As an example, consider the alignment of the main spindle of a milling machine with the bore of the support for the overhanging arm (Fig. 26a, b). With the mandrel in the bore of the overhanging arm and the dial gauge holder in the taper of the spindle, the feeler is adjusted so that it touches the mandrel. The main spindle is turned slowly and the reading of the dial gauge is observed at four points on a vertical diameter of a_1, a_2, and on a horizontal diameter b_1, b_2. The difference between the two a readings and that between

the two *b* readings is twice the eccentricities of the mandrel in the vertical and horizontal directions respectively. In the first position *A* the bracket has a distance of 12 in. (300 mm.), in the second *B* 20 in. (500 mm.) from the spindle nose.

It is possible to measure the alignment of the spindle and the bore in the mandrel support with the slip bushing method, shown in Fig. 27. The feeler of the dial *M* touches the outer end of the mandrel *D*. Before the test it is necessary to determine whether the mandrel runs true or not and, if necessary, to measure the deviations of the end. Any such eccentricity must be taken into account as well as the sag of the mandrel due to its own weight and

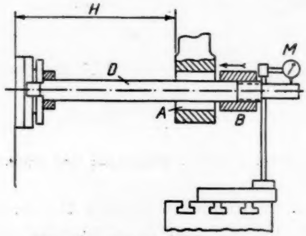


Fig. 27.—Slip bushing method.

to that of the sliding bush. The bush *B* has a sliding fit in the bore of the support and the arbor has a sliding fit in the bush *B*. If the bush *B* is slid into position in the bore of the support, the dial gauge will indicate the movement of the arbor. If there are several supports, the foregoing procedure must be repeated for each at several distances from the spindle nose.

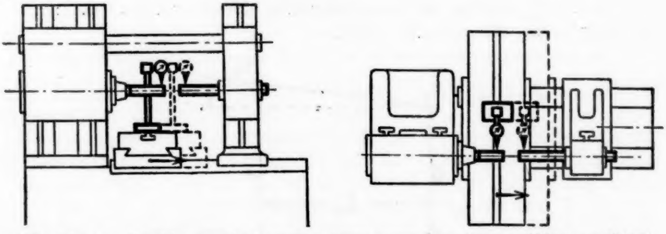


Fig. 28a, b.—Double mandrel method from common plane (milling machine).

In the case of the lathe, the alignment of the main spindle with the external diameter of the tailstock sleeve is not essential but the axes of the two internal tapers must be aligned. In good class machines, however, the external cylinder and internal taper of the sleeve is exactly concentric.

In the case of grinding and milling machines, it is often more convenient to check the alignment of the axis with a common plane of reference. This should only be done if the hollow mandrels used are less than 8 in. long so that their sag is negligible. (Fig. 28a, b).

This method is a form of the two mandrel test which is sometimes used to check the alignments of the main spindle and turret head holes of a capstan lathe (Fig. 29). In such a case, the trammel readings may be replaced by using a dial gauge to check the two axes

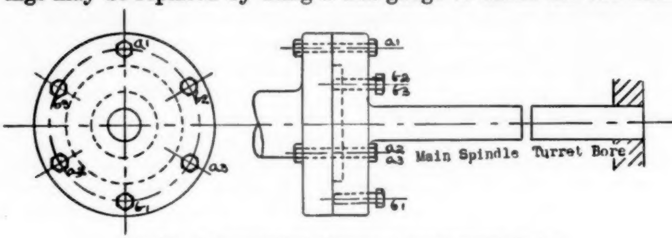


Fig. 29.—Two-mandrel alignment test (capstan lathe).

with reference to a single plane, usually the surface of the bed. In the application of this method to a capstan lathe, the following possible sources of error arise—

(1) Natural sag of the mandrel. A mandrel of 1 in. diameter and 12 in. long has a sag of approximately 0.0004 in.
(2) Geometrical inaccuracies of the mandrel. Lack of parallelism between cylindrical portion of mandrel and taper shank, lack of cylindricity of the cylindrical section, etc.
(3) Imperfect location of mandrel in spindle. There can hardly be 100% bearing between mandrel shank and its seating.
(4) Errors in the spindle itself.

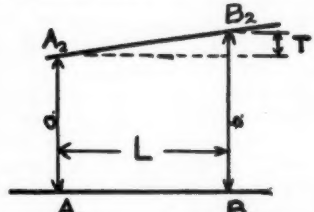


Fig. 30.—Differences of height-checking, parallelism of axes.

Similar errors may arise in the case of the second mandrel which is fixed in the turret. The whole of the two mandrel test must be conducted with the utmost care by an intelligent and experienced

inspector, who is aware of these difficulties and can take appropriate precautions.

(4) *Parallelism.* Parallelism and alignment belong together; it is the most important and most frequent measurement. The parallelism of two axes or two surfaces or of a single axis and surface may be checked as shown in Fig. 30. The distances *a* and *b* between the points A_1, A_2, B_1, B_2 must be measured together with the distance *L* between the points A_1 and B_1. From these results the required inclinations can easily be determined. An alternative method of checking the angle is to use the spirit level. In most cases it is necessary to determine the inclination by measuring the angles in two planes, usually vertical and horizontal. If, however, the position of one part, for example, the table or tailstock is adjustable in a given plane, it is only necessary to check the inclination in a perpendicular plane.

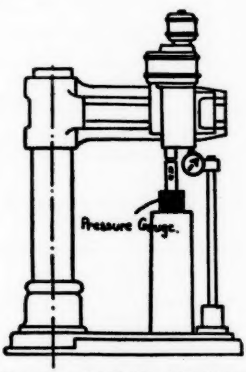


Fig. 32.—Vertical thurst to check the deflection of arm and column.

(5) *Perpendicularity.* Perpendicularity is checked either with a trammel arm or directly with a square.

Trammel readings are illustrated in Fig. 43 for the lathe, Fig. 53 for the milling machine, Fig. 76 for the radial drilling machine.

The use of the square is shown in Fig. 54a, b, for the milling machine in Fig. 67, for the grinding machine in Fig. 78 and 79 for the radial drilling machine.

B. Accuracy of Workpieces Machined with Fine Finishing Cuts.

In view of the wide range of machine tools, it is difficult to prescribe definite *machining tests.* The demands of different users vary considerably. The machine must always be capable of producing a fine finished workpiece without vibration marks which conforms to the

limits of accuracy prescribed at the end of each acceptance test chart. The form of the test workpiece should be as prescribed in the acceptance charts or as fixed by a written contract.

Drilling machines should be capable of producing holes perpendicular to the base parallel to each other and within prescribed limits for roundness. Instead of performing actual drilling tests it is preferable to measure the maximum deflection of the arm relative to the table or base with the saddle in the extreme position. This deflection must be within the limits prescribed in the test charts.

Diameter of drill.	*Proposed feed rate.*	*Vertical thrust.*
inches.	inch/rev.	lb.
$\frac{1}{4}$ ...	0.004	250
$\frac{1}{2}$ ...	0.008	500
$\frac{5}{8}$ ...	0.01	800
$\frac{3}{4}$ ...	0.012	1,200
1 ...	0.014	1,650
$1\frac{1}{4}$ ...	0.015	2,000
$1\frac{1}{2}$ ...	0.016	2,700
$1\frac{5}{8}$ ...	0.017	3,100
$1\frac{3}{4}$ ...	0.018	3,600
2 ...	0.018	4,000
$2\frac{1}{4}$ ...	0.019	4,600
$2\frac{3}{8}$ ...	0.019	5,000
$2\frac{1}{2}$ ...	0.02	5,600
$2\frac{3}{4}$ ...	0.02	6,000
3 ...	0.02	6,600

Fig. 31.—Table of drill-thrust.

To conduct these tests it is necessary to know the axial force exerted by the various drills when in operation.

The table (Fig. 31) shows the vertical thrust on the drill corresponding to different drill diameters and given feed rates. The table refers to mild steel of 35 to 45 tons per sq. inch.

To obtain the deflection of the arm, it should be set in its top position with the carriage at the extreme end of the arm (Fig. 32). A thrust gauge must be supported below the drill spindle. A dial gauge fixed to the base plate should be arranged with its feeler touching any surface on the lower side of the saddle except surfaces on parts of the feed gear. The feed hand wheel should be turned

until the pressure gauge indicates the desired value, then the corresponding reading of the dial gauge should be observed.

In the case of punch and power presses the accuracy of the ways must be maintained when the machine is subjected to the maximum load, for this is essential if the punch is not to be damaged in the die.

C. Power and Efficiency of the Machine.

Every machine tool should be so rigidly constructed that the various parts will not deflect unduly when the machine is subjected to its maximum load. Where a machine is not intended to be used in a certain manner, this should be definitely stated in a letter to the user or in the catalogue which gives particulars of the machine, for instance many small and medium sized lathes are not built in such a way that the maximum chip section can be cut when the machine is operating at its maximum diameter (swing).

Nowadays ever-increasing speeds are accompanied by diminished cutting forces. The relation between speed, cutting force and power consumption is $P = \dfrac{F \times v}{33{,}000}$ h.p. where

F = the cutting force in lbs.,
v = the cutting speed in ft/minute.

A mean efficiency for the whole machine is assumed to be 0.67, then the formula becomes $P = \dfrac{F \times v}{22{,}000}$ h.p

The power consumption is measured by recording volts and amperes.

It is advisable in all machines, where overload may occur, to have a safety device such as a friction clutch or a shear pin.

General Inspection.

All machines which conform to the limits prescribed in the test charts should have their general performance checked. This can be conveniently done by answering the following questions :—

(1) Did the machine run satisfactorily at all speeds ?
(2) Do all horizontal and vertical feeds work correctly ?
(3) Do the gears run without noise ?
(4) Is the machine free of vibration marks during the cutting operation ?
(5) Is the lubrication equipment inspected and in good condition ?
(6) Are the bearings well adjusted ? Do the carriage guidances work without backlash, and is the function of rotating and oscillating movements correct and uniform ?

(7) Do the safety clutches or other safety devices function correctly?

(8) Are the dial rings and the fine adjustments by hand correctly divided and marked?

(9) Is there any objection regarding the service of the machine?

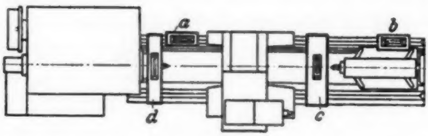


Fig. 33.—Levelling the lathe bed.

Application of General Rules of Inspection.

How the foregoing general measuring instructions can be applied to particular machines is shown in the following examples, which include brief outlines of the tests applied to—

(1) Lathes,
(2) Milling machines,
(3) Grinding machines,
(4) Radial drilling machines.

I. LATHE TESTS.

(a) *Levelling the bed*—
(1) longitudinally,
(2) transversally.

To test the bed longitudinally the spirit level should be placed at points *a* and *b* on the rear ways of the bed, facing away from the front of the machine. This is desirable, because the front ways are intentionally convex, whereas the rear way is generally flat. The bed should also be tested transversely by placing levels in positions (*c*) and (*d*) shown in Fig. 33. It is preferable to use two levels at the same time, one lengthwise and the other crosswise, so that when the machine is being levelled in one direction the effect in a direction at right angles can be observed immediately. Twist in the bed is not permitted in either direction, for its presence would prevent the lower surfaces of the carriage from bearing. Thus the deviations must all be positive or all negative.

The four corners of the bed should now be in the horizontal plane (cf., acceptance chart of lathe tests, Nos. 1 to 3), and other tests can be conducted.

(*b*) *Checking the Ways and Fundamental Movements.* The bed must be straight longitudinally. With beds up to 9 ft. (3 m.) in length, the setting of a level on the guide of the carriage is suf-

ficient. If necessary an intermediate block or bridge may be used (see Fig. 13). The bearing base of the level must always be parallel to the axis of the vee-shaped way. The straightness of the way is checked by placing the level at intervals of 12 in. along the whole length of the bed. In a similar way the opposite surface is checked.

With machines of more than 9 ft. (3 m.) between centres, other means of testing the ways must be chosen such as taut wire, telescope, autocollimator, comparison with long straightedges, etc. (see Figs. 2 to 7).

The convexity to the front way caused the displacement of the bubble to be in opposite direction for each half of the way. The bubble displacement should always be towards the centre of this

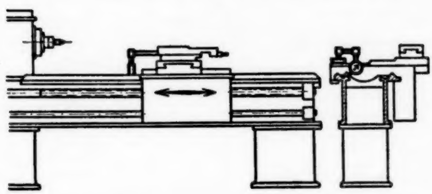


Fig. 34.—Tailstock guideways to carriage movement.

way (see Fig. 9). But in both cases only one convex shape is allowed in the direction towards the middle of the bed, while the back surface is usually made flat. It is advisable, then, to take this flat guidance as the starting surface for all other measurements.

The straightness of the tailstock guideways, their surface quality and their parallelism with the carriage ways is readily tested with the dial gauge clamped to the carriage (Fig. 34). As the feeler of the dial gauge passes over the surface, it will show quite clearly every minute depression on the mottled surface, which must be of the finest quality in order to withstand the severe wearing conditions

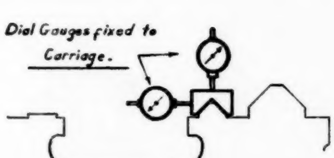


Fig. 35.—Feeler instruments on intermediate block to measure horizontal and vertical errors at the same time.

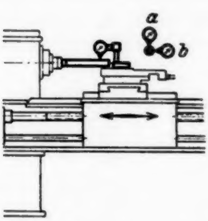


Fig. 36.—Spindle to carriage guideways.

during machining between centres. Another way of checking the parallelism of the guideways of carriage and tailstock is by inserting intermediate blocks, as shown in Fig. 35, or by using the tailstock itself as such a block. A disadvantage of this method is that it shows the general directions of the ways but gives no indication of surface quality, a factor of great importance to the user.

(c) *Checking the relation of the axes of rotation to other important units.*

(1) Parallelism of the *carriage guidance* with the (*a*) tailstock guidance (Fig. 34) plane to plane; (*b*) working spindle (Fig. 36) plane to axis; (*c*) external diameter of sleeve (Fig. 37) plane to axis; (*d*) internal taper of sleeve (Fig. 38) plane to axis; (*e*) axis of lead screw (Fig. 39) plane to axis.

(2) The parallelism of the main spindle with the tool slide also requires checking (Fig. 40).

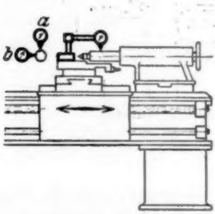


Fig. 37.—Tailstock sleeve to carriage guideways.

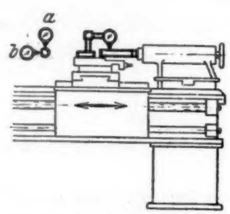


Fig. 38.—Tailstock axis to guideway.

The measurement (1) (*a*) has been discussed (see Fig. 34) and the measurements (1) (*b*) to (1) (*e*) are all performed in a similar manner so that it is only necessary to describe in detail the case (1) (*b*) (Fig. 36).

Place the mandrel in the spindle taper and fix the dial gauge to the carriage. Adjust the dial gauge so that the feeler is touching the mandrel surface, turn the spindle slowly until the mean position is reached in which the effect of eccentricity, etc., is eliminated. Move the carriage parallel to the mandrel for the prescribed length

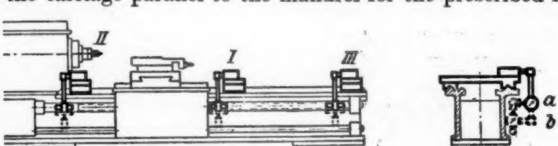


Fig. 39.—Leadscrew to guideway.

(4 in. to 12 in.) and note the dial gauge reading, at the beginning and end of this movement. These observations must be made in both the horizontal and vertical planes. The main spindle must be run in for about an hour at its highest speed (warmed up) before the foregoing measurements are made. If this is not done, the spindle will not be at its normal working temperature (85° to 105°F. =30° to 40°C.) and consequently will not be in its normal working position. The permissible inclination of the axis of the spindle to the guiding surfaces of the carriage are (*a*) a rise towards the free end of the mandrel to allow for wear of the main bearings, (*b*) an inclination of the free end of the machine to allow for deflection due to the cutting forces.

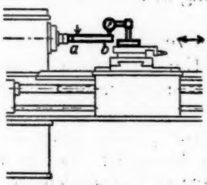


Fig. 40.—Upper slide to spindle.

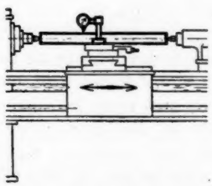


Fig. 41.—Checking heights of main and tailstock spindle.

It is essential that the tailstock sleeve be properly clamped in position while its parallelism with the carriage way is being checked (Fig. 37), because the clamping stress influences the position of the sleeve.

Besides testing parallelism of axes, it is often necessary to check the relative position of axes. For example the spindle and tailstock of a lathe must not only be parallel, their axes must be in the same straight line (aligned). Another example is the half nut and bearings of the lead screw.

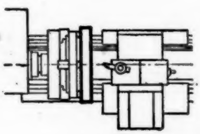


Fig. 42.—Facing.

In order to check the height of the main spindle and of the taper in the tailstock sleeve, a hollow mandrel (12 in. to 20 in. long), accurately centred, should be inserted between centres (Fig. 41). A dial gauge fixed to the carriage with its feeler touching the top

of the mandrel should be observed as the carriage is moved along the mandrel (It is only permissible for the tailstock end to be higher). Before making the test, the main spindle must be warmed up by an adequate period of running-in at full speed.

To check the alignment of the half nut and bearings of the lead screw place the carriage in its middle position on the bed and close the half nut. Clamp the dial gauge rigidly to a bridge which bears on the back surface of the bed and is guided by the front main carriage way only. The dial gauge feeler is applied directly to the top of the thread so that the alignment to the right of the carriage can be checked by reading in positions (I) and (III) (Fig. 39), and that to the left by readings in positions (I) and (II). The lead screw should be turned to check the true running of the external diameter by a dial gauge.

In order to determine whether the movement of the cross-slide of a lathe is perpendicular to the axis of the main spindle, a surface plate may be faced and checked or the usual method using the turn-over arm may be employed.

To check the accuracy of a lathe for *facing* purposes it is necessary to clamp a workpiece to a threaded flange located on the spindle and to machine the surface of the workpiece with a fine finishing cut taken from the axis to the outer surface. The faced surface is then checked by placing a straight-edge on two equal slip

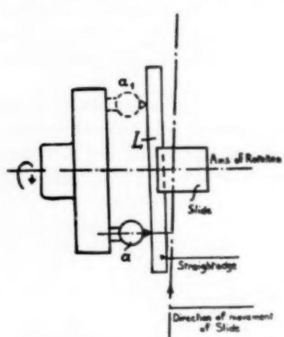


Fig. 43.—Perpendicularity of cross-slide movement to axis of spindle.

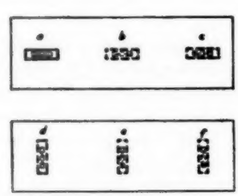


Fig. 44.—Levelling the table of milling machine.

gauges situated at either end of an external diameter and inserting a third slip gauge of the same size between the straight-edge and the surface at a point near the centre (Fig. 42). The third slip gauge must enter, for the only permissible deviation of the faced surface from a perfect plane is a slight concavity. It is incorrect to check

this movement of the cross-slide by fixing a dial gauge to the tool holder and traversing the faced surface. Obviously, if this is done, the dial gauge will follow exactly the same path as the tool and its reading will, therefore, be zero.

Another method of checking the movement of the cross-slide is to clamp a straight-edge to the upper slide and to fix a dial gauge to the face plate. The straight-edge must be adjusted at right angles to the axis of rotation by obtaining two equal dial gauge readings in two positions 180 degrees apart in the horizontal place (Fig. 43). When the straight-edge is so adjusted, it is possible to check the straightness and perpendicularity of the motion of the cross slide by moving it and the straight-edge across the feeler of the dial gauge.

II. Horizontal Milling Machine Tests.

(*a*) *Levelling the Worktable* (Fig. 44):

(1) Longitudinally.

(2) Transversally.

The worktable must be flat, longitudinally, and transversely. A spirit level, graduated in scale divisions representing 0.0005 in. per foot, is placed directly on the table at points about 10 to 12 in. apart, at *a*, *b*, *c* for the longitudinal test, and at *d*, *e*, *f* for the transversal test. Twist is permitted according to the admissible tolerances

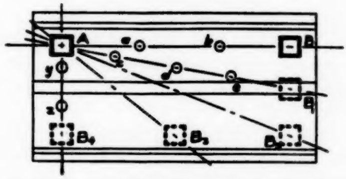


Fig .45.—Checking flatness of table by straight-edge, slip gauge, and internal feeler.

(see tests No. 1 and 2 of Acceptance Charts for Milling Machines). The deviations of the bubble are observed and should be noted on a diagram of the table. This test checks the flatness of the machine table and represents at the same time the levelling of the machine.

Another method of checking the flatness of a not too large table is to insert equal slip gauges A and B between the machine table

and each end of an accurate straight-edge. Variations in the gap between the straight-edge and the table are measured with an internal micrometer. The straight-edge and blocks should be moved to positions such as those indicated by the dotted lines B_1, B_2, B_3, and the measurements should be made at points such as *a*, *b*, *c*, *d*, *e*, etc. (Fig. 45). These variations represent undulations on the surface. This procedure is very slow and requires extreme care.

If the table of a milling machine is not flat, the workpiece may deflect, when it is fastened to the table. After milling, when the job is taken from the table, it will spring back and the milled surfaces will no longer be flat. For this reason it is necessary to use rigid

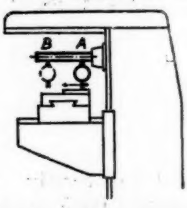


Fig. 46.—Main spindle against table surface.

Fig. 47.—Table straightness.

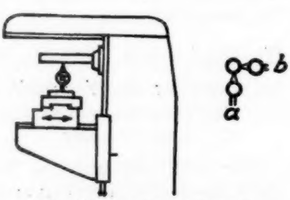


Fig. 48.—Cross movement against main spindle.

workpieces when conducting the practical tests on a milling machine (cf. Acceptance Test Charts on Milling Machines, No. 22 to 24).

(*b*) *Checking the Relation of the Axis of Rotation to Other Important Units and Fundamental Movements.*—In the case of the *horizontal milling machine*, parallelism between the following parts must be checked :

(1) Face of table and main spindle, plane to axis.
(2) Face of table and its longitudinal motion, plane to plane.
(3) Cross-motion of table and main spindle plane to axis, (*a*) in the vertical plane, (*b*) in the horizontal plane.
(4) Central T-slot of the table and its longitudinal motion, plane to plane.
(5) (*a*) Supporting arm bore and table surface in vertical plane, plane to axis.
(*b*) Supporting arm bore and table movement in horizontal plane, plane to axis.

The alignment of the main spindle with the bore of the supporting arm has already been discussed (see Fig. 26*a*).

(1) Parallelism between the table face and the axis of the main spindle is checked in the manner shown in Fig. 46. The table is adjusted in the horizontal plane by a spirit level. The table is then set in its mean position longitudinally and the mandrel 12 in. long

fixed in the spindle taper. A dial gauge is set on the machine table, and the feeler adjusted to touch the lower surface of the mandrel. The mandrel is then turned so that eccentricities and other errors are eliminated in the vertical plane. With the mandrel in this mean position the dial gauge readings at A and B are observed, the stand of the dial gauge being moved, while the machine table remains stationary. The base of the dial gauge must be sufficiently long to extend to points A and B when the table itself is too narrow.

(2) The investigation of the flatness of the table by means of the spirit level can be recorded in the form of a diagram giving heights of the surface undulations above a perfect plane. A dial gauge fixed to the body or spindle of the machine can then be

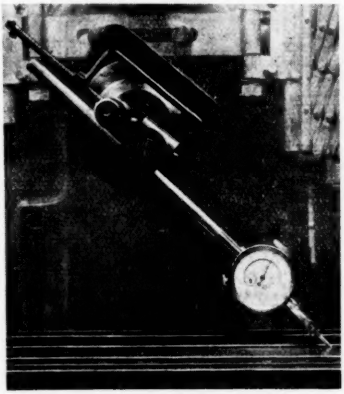


Fig. 49.—Checking T-slot with angle indicator.

adjusted with its feeler bearing directly upon the surface of the machine table and, as the latter is moved longitudinally, deviations from parallelism between the table surface and its longitudinal motion can be directly observed. If the table is uneven it is necessary to place a straight-edge on its surface and let the dial gauge feeler rest on the top surface of the straight-edge instead of bearing directly on the table surface. The length of the straight-edge must be equal to that of the longitudinal movement of the table (Fig. 47).

(3) To check the parallelism between the cross movement of the table and the main spindle, the table should first be set in its mean position longitudinally. A dial gauge fixed to the table should have its feeler adjusted to touch the surface of a mandrel 12 in. long inserted in the spindle taper and turned to the appropriate mean

position of its eccentric error. The table is moved crosswise and the error measured: (*a*) in the vertical plane, (*b*) in the horizontal plane (Fig. 48).

(4) The T-slot should be well machined on the internal vertical surfaces throughout its entire length because jigs and fixtures are located by the T-slot. Access to these surfaces with the feeler of the dial gauge is difficult, and it is preferable to use the angle lever attachment which can be fitted to the dial gauge and which readily enters the slot (Fig. 49). This facilitates the location of waves, holes, and other imperfections which may occur on the walls of

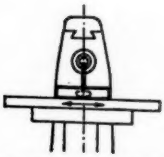


Fig. 50.—Bracket with tenon to check the middle T-slot of the table.

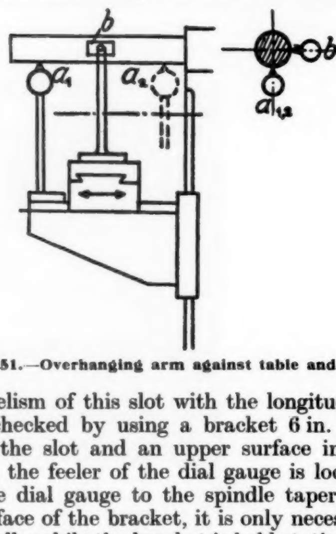


Fig. 51.—Overhanging arm against table and knee.

the slot. The general parallelism of this slot with the longitudinal movement of the table is checked by using a bracket 6 in. long with a tenon which enters the slot and an upper surface in the vertical plane against which the feeler of the dial gauge is located (Fig. 50). Having fixed the dial gauge to the spindle taper and adjusted its feeler to the surface of the bracket, it is only necessary to move the table longitudinally while the bracket is held stationary by the hand of the operator and read directly on the dial gauge deviations from parallelism. During this process the tenon slides along the slot, eliminating the effects of local errors.

(5*a*) To check parallelism of the bore of the supporting arm and the table surface (parallel to the knee), the arm is clamped in its extreme position. The height of this arm above the knee should then be checked as shown in Fig. 51 at points a_1 and a_2 on the knee.

(5*b*) To check parallelsim of the supporting arm bore and the table movement in the horizontal plane, the dial gauge should be fixed to the table and its feeler adjusted against the side of the overhanging arm (Fig. 51*b*). It is then only necessary to move the table transversely and read deviations from parallelism directly on the dial gauge.

If it is also necessary to check deviations from parallelism between the main spindle and the guiding surfaces of the overhanging arm—one bar, twin bar, box shape—it may be done as shown in Fig. 52. Having clamped the overhanging arm in its extreme extended position, the dial gauge should be fixed to the arbor support, the feeler being adjusted so as to touch the top or the side of the test mandrel. The arbor support can then be moved along the overhanging arm and deviations from parallelism observed on the dial gauge. Where the overhanging arm takes the form of a single cylindrical bar, the arbor support, carrying the dial gauge, must be swung about the overhanging arm as indicated in Fig. 52. This

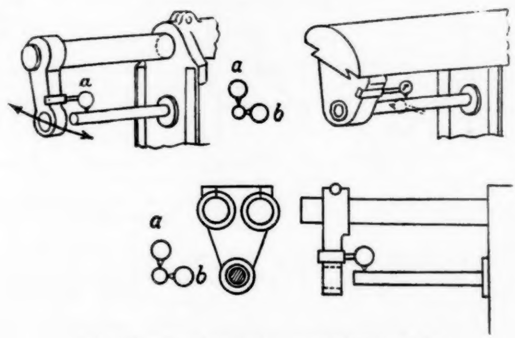


Fig. 52.—Overhanging arm against spindle.

should be done for several positions of the arbor support on the overhanging arm, the peak reading of the dial gauge being taken in each case.

In the case of the milling machine, the *perpendicularity* of the following surfaces must be checked:

(1) locating slot in table surface and axis of main spindle (plane to axis).
(2) Table surface and
  (*a*) Front guiding surface of knee support (plane to plane).
  (*b*) Side guiding surface of knee support (plane to plane).

(1) To check the perpendicularity of the locating slot and the axis of the main spindle, the table should be arranged in the middle position of its longitudinal movement, and a bracket with a tenon at least 6 in. long inserted in the locating slot as shown in Fig. 53. A dial gauge should be fixed in the spindle taper, the feeler being adjusted to touch the vertical face of the bracket. Observe the reading on the dial gauge when the bracket is near one end of the

table, then swing over the dial gauge and move the bracket so that the corresponding reading can be taken near the other end of the table.

(2) Arrange the table in its central position lengthwise and crosswise and clamp the knee to the stand. Fix a square with an arm about 12 in. long to the table surface and attach a dial gauge to the spindle taper in such a way that the feeler rests on the arm of the square near the top, as shown in Fig. 54*a*, *b*. Observe the indication of the dial gauge. Loosen the knee and move the table

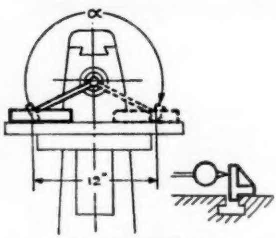


Fig. 53.—Trammel reading of T-slot.

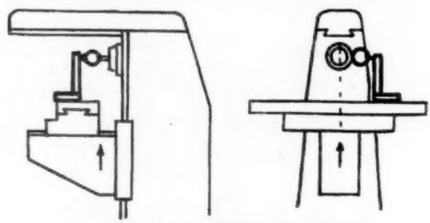


Fig. 54a, b.—Perpendicularity of movement of knee.

upwards about 12 in.; reclamp the knee and again observe the indication of the dial gauge. The difference of these two readings is a direct indication of the perpendicularity. The readings of the dial gauge should be the same for any given position of the knee irrespective of whether the latter is free or clamped. In the case

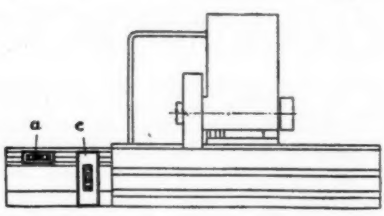


Fig. 55.—Levelling the bed of a grinding machine.

of the foregoing tests it is advisable to observe five sets of readings and take the average. It is, of course, essential to use a square that has been carefully checked.

As shown in Fig. 54, the above tests should be conducted for two positions of the dial gauge and square: (*a*) with the square facing the front guiding surface of the knee, (*b*) with the square facing the side guiding surface of the knee support.

III. External Grinding Machine Tests.

(*a*) *Levelling the Bed* (Fig. 55)—(1) longitudinally, (2) transversely.

The spirit level should be placed longitudinally and transversely as shown at *a* and *c* respectively. If the level is not long enough it should be supported on a bridge-piece or straight-edge when checking position *c*. If the worktable is not to be taken off the machine, the table should be arranged at the right hand end of the bed, while (*a*) and (*c*) are observed, and then moved to the left hand end, while observations similar to (*a*) and (*c*) are taken at the right hand end of the bed. If the worktable can be removed, it is advisable to

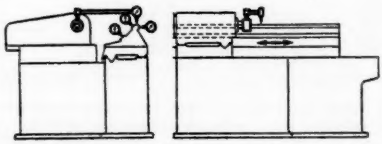


Fig. 56a.—Parallelism of the four ways-table with bed ways.

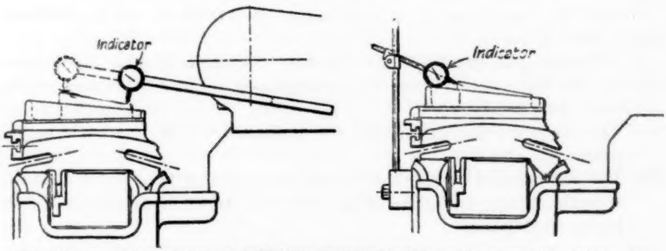


Fig. 56b, c.—Parallelism of grinding machine tables with ways (b)—table with bed (c) master edge with table.

conduct tests (*a*) and (*c*) at intervals of 12 in. along the whole length of the bed.

(*b*) *Checking the Way and Fundamental Movements.* In levelling the bed, as already described, Fig. 55, the flatness of the bed in a longitudinal direction is also checked. Long beds should be supported on flat steel wedges at intervals not greater than 3 ft.

The distribution of load between the front and rear ways of cylindrical grinding machines is always more even than that of the lathe. The units mounted on the bed are not so heavy as the lathe headstock and tailstock, and the long grinding table distributes the load very well. The grinding forces themselves are quite small, being less than 220 lb. on heavy roughing cuts, and therefore have little effect upon the deflection of the bed. The bases of long grinding

machines must be freely supported on concrete foundations unless they are mounted on cast-iron foundation plates which are grouted.

The straightness of the headstock and tailstock ways must be carefully checked. The dial gauge is fastened on the bed, the plunger resting on the top and the sides of the table, set up in zero position, which moves longitudinally on its ways so that the whole length is checked. Fig. 56*a* shows an American four-ways table,

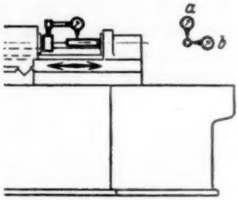


Fig. 57.—Main spindle against table-movement.

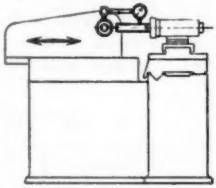


Fig. 58.—Main spindle in swivel headstock of universal grinder against adjusting movement of grindstone.

Fig. 56*b* a British machine. The allowable error on a 40 in. length is 0.0005 in., and rises to a maximum of 0.0013 in. on a grinding length of 6 ft. or over.

(*c*) *Checking the Relation of the Axis of Rotation to other Important Units.* In the case of *external grinding machines* it is necessary to check the *parallelism* of :

(1) The ways of the table and the headstock and tailstock ways, plane to plane.

(2) The movement of the table and the internal taper of the main spindle, plane to plane, Fig. 57 : (*a*) in vertical plane, (*b*) in horizontal plane.

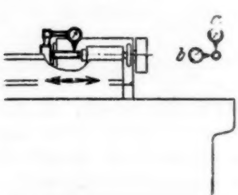


Fig. 59.—Tailstock spindle against table movement.

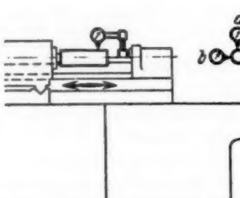


Fig. 60.—Grinding spindle against table movement.

(3) Main spindle in swivelling headstock and adjustable grindstone support ; axis to plane. Measurements to be taken in the vertical plane and in the 90° position of the headstock, Fig. 58.

(4) The table movement and the internal taper of the tailstock sleeve, axis to plane, Fig. 59 : (*a*) in a vertical plane, (*b*) in a horizontal plane.
(5) Table movement and axis of grinding spindle, axis to plane, Fig. 60 : (*a*) in a vertical plane, (*b*) in a horizontal plane.
(6) Table movement and axis of internal grinding spindle, axis to plane, Fig. 61 : (*a*) in a vertical plane, (*b*) in a horizontal plane.

(1) The procedure for checking the parallelism of the table ways and the headstock ways has already been explained in connection with the straightness and flatness.

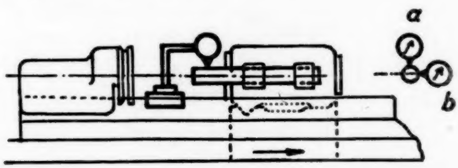


Fig. 61.—Internal grinding spindle against table movement.

(2) (Fig. 57). Set the upper table in the zero position and place a mandrel 12 in. long in the taper of the main spindle. Fix the dial gauge with its feeler on the mandrel surface and, if the machine has a rotating spindle, turn the mandrel to the mean position of its eccentric error. Move the table so that the feeler passes along the mandrel and note the indications of the dial gauge. The only permissible errors are : (*a*) mandrel rising towards free end, (*b*) free end of mandrel directed towards grindstone.

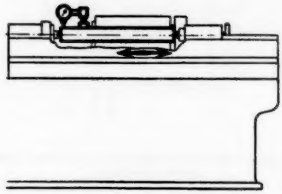


Fig. 62.—Alignment of main spindle against tailstock sleeve.

(3) (Fig. 58.) This test is only necessary in the case of universal grinding machines. The procedure is similar to that of No. 2 above, the dial gauge being clamped to the grindstone carriage which is moved along the test length. The movement through 90° is given with sufficient accuracy by the graduations on the swivel table,

for in this instance it is only the vertical deviation which has to be measured and extreme accuracy in the angular movement is not required. The only permissible error is a rise towards the free end of the mandrel. During this test the height of the two spindles is tested at the same time. They should be the same in both the zero and 90° position.

(4) (Fig. 59.) Having set the table to its zero position and inserted a mandrel 12 in. long in the sleeve of the tailstock, which is clamped in its inward position, a dial gauge should be fixed and its feeler adjusted to touch the surface of the mandrel. The table

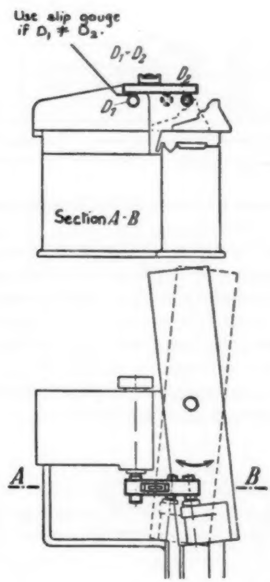


Fig. 63.—Checking height of main spindle and external grinding spindle. Spirit level method.

should be moved in a longitudinal direction and the indications of the dial gauge observed. The only permissible errors are: (*a*) mandrel rising towards free end, (*b*) free end of mandrel directed towards the grindstone.

In the case of small machines where the sleeve of the tailstock moves only a short distance in clamping and releasing workpieces this test can be omitted.

(5) (Fig. 60.) A mandrel 4 in. long should be fixed concentrically to the grinding spindle. The method of fixing being dependent upon the design of the spindle nose. A dial gauge located on the table or measuring bridge should have its feeler resting on the mandrel surface. When the mandrel has been turned to the mean position of its eccentric error, the table should be moved longitudinally over the full length of mandrel and the indications of the dial gauge

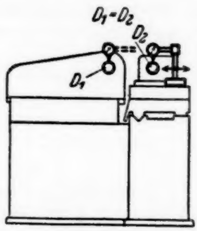


Fig. 64.—Checking height of main spindle and external grinding spindle. Dial gauge method.

observed. The only permissible errors are: (*a*) mandrel rising towards free end, (*b*) free end of mandrel directed towards the grindstone.

(6) (Fig. 61.) A mandrel with a cylindrical portion 4 in. long should be located in the bearing of the internal grinding spindle and adjusted to the mean position of the eccentric error. A dial

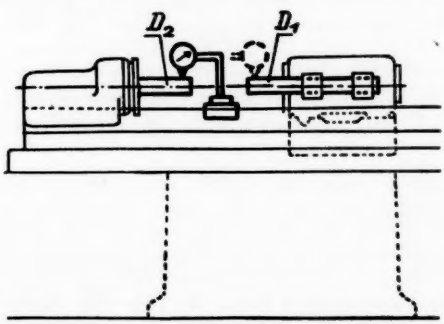


Fig. 65.—Checking height of main spindle and internal grinding spindle.

gauge mounted on the table or on a bridge and with its feeler resting on the mandrel surface will indicate errors in parallelism, as the table is moved along the test length.

The *height of the axes* of the two spindles is checked in a way similar to that already described for the lathe, Fig. 41, or the milling machine, Fig. 26 to 27.

In the case of the grinding machine it is also necessary to check the heights of the following spindles :

(1) Axis of spindle and tailstock taper, Fig. 62.
(2) Main spindle and external grinding spindle, Figs. 63 and 64.
(3) Main spindle and internal grinding spindle, Fig. 65.
(4) Grinding spindle throughout its cross movements, Fig. 66.

(1) (Fig. 62.) Set hollow test mandrel of 12 in. to 32 in. length between the centres and adjust the dial gauge to touch the upper surface of the mandrel. Move the table longitudinally and observe the indications of the dial gauge. The only permissible error is a rise at the tailstock end.

(2) (Figs. 63 and 64.) Two mandrels, D_1 and D_2, with cylindrical test lengths 4 in. long and of exactly the same diameter are located in the grinding spindle and the main spindle respectively. If the grinding spindle has a cylindrical projection this can be used instead of one of the mandrels, the difference in diameter between this

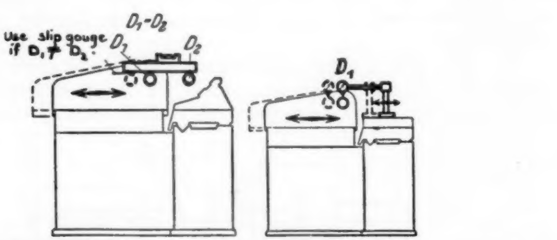


Fig. 66a, b.—Checking height of grinding spindle during its cross movement.

projection and the remaining mandrel being adjusted by slip gauges. With the grinding carriage in the middle of its way, the mandrels D_1 and D_2 should be adjusted to the mean position of their eccentric error. Then proceed by one of the following methods : (*a*) (Fig. 63.) Put straightedge over both mandrels and spirit level on straightedge. Observe indication of spirit level. (*b*) (Fig. 64.) Mount dial gauge on upper table or, if table is slanting, on a bridge, and adjust the feeler of the dial gauge so that it rests on the top of mandrels D_1 and D_2 in succession. Observe the readings of the dial gauge in each of these positions.

The above tests must be performed in both the extreme angular positions of the swivelling table. (Fig. 63).

(3) (Fig. 65.) Mandrels D_1 and D_2 with cylindrical test lengths of 4 in. and exactly equal in diameter should be inserted in the bearing of the internal grinding spindle (D_1) and the work headstock (D_2) respectively. Both mandrels should be adjusted to the mean position of their eccentric error and a dial gauge located on the surface of the table or on a bridge should be moved so that its feeler rests in succession on the free ends of both mandrels. Observe the indications of the dial gauge.

(4) (Fig. 66*a*,*b*.) Set the grinding carriage to its extreme back position and insert mandrel with a cylindrical test length of 4 in. in the grinding spindle. Turn the mandrel to the mean position of its eccentric error.

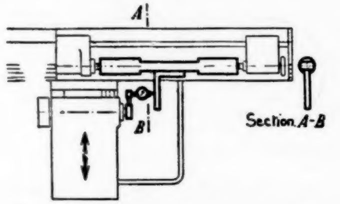


Fig. 67.—Perpendicularity to work axis of in-feed movement of grindstone carriage.

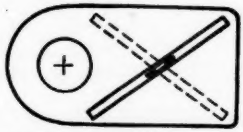


Fig. 68.—Levelling the base plate of radial drill.

There are then two methods of performing the test: (*a*) Insert a mandrel in the headstock spindle equal in diameter to that in the grinding spindle and place a straight-edge and spirit level across the top of both mandrels as shown in Fig. 63. Move the grinding spindle and observe the indications of the spirit level. (*b*) Place a dial gauge on the machine table and pass its feeler across the top of the mandrel D_1. Note the peak reading of the dial gauge. Move the grinding

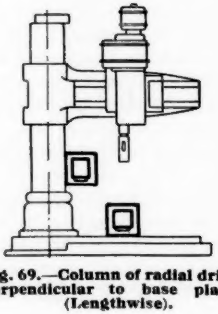


Fig. 69.—Column of radial drill, perpendicular to base plate. (Lengthwise).

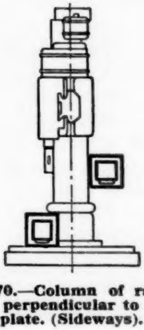


Fig. 70.—Column of radial drill, perpendicular to base plate. (Sideways).

spindle to the other end of its stroke and observe the new reading of the dial gauge (as shown in Fig. 64).

The last test for the grinding machine is to check the *perpendicularity* of the in-feed movement of the grindstone carriage to the axis of the workspindle which must be adjusted parallel to the bedways in the zero position.

Set the upper table in the zero position and the grinding carriage in its extreme back position, Fig. 67. Insert a mandrel between the centres. It is convenient to have a pair of flats on the mandrel parallel to its axis of about $\frac{3}{4}$ in. wide and 12 in. long. Place the base of a square against one of the flats and adjust the feeler of the dial

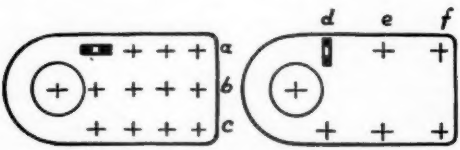


Fig. 71.—Flatness of base plate of radial drill.

gauge, which is fastened to the carriage, so that it rests on free arm of the square. Move the carriage throughout the entire test length and observe the indications of the dial gauge.

IV. Radial Drilling Machine Tests.

(*a*) *Levelling*: (1) *the base plate,* (2) *the column.*

(1) *Levelling the Base Plate* (Fig. 68). Arm and saddle are brought into their middle positions (half column or arm). A straight-edge of sufficient length (about 40 in., 1,000 mm.) is placed along both diagonals of the base plate, and the spirit level is placed on the middle of the straight-edge. Convexity of the base plate is not permitted.

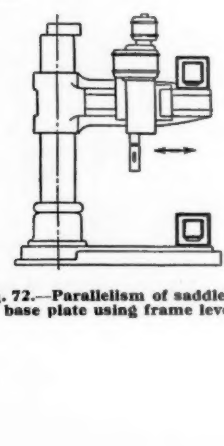


Fig. 72.—Parallelism of saddle with base plate using frame level.

Fig. 73.—Flatness of vertical front surface.

(2) *Adjusting the Column* (Figs. 69 and 70). With the arm in its middle position, the column must stand at right angles to the base plate. The frame spirit level with V-shaped base must be pressed on the front and the side of the column in turn. The spirit level must be in the correct checking plane, which passes through the axis of the column and the centre of the base plate. The only deviation permitted is a forward inclination of the column, so that the angle between the axis of the column and the base plate surface is less than 90°.

If the base plate is in the form of an angle or a cross, the arm, in turning round the column, must not swing up or down an amount greater than that prescribed for the appropriate radii in the test charts.

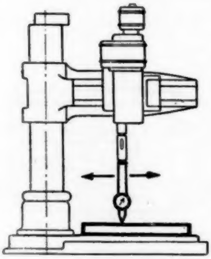


Fig. 74. — Parallelism of saddle movement to base plate using straight-edge and dial gauge. (Instead of Fig. 72).

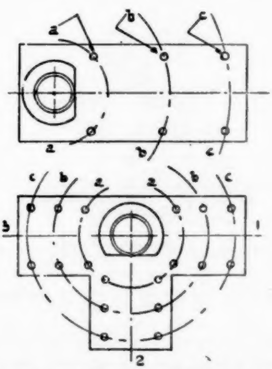


Fig. 75.—Checking parallelism of whole range of saddle movement with base plate.

(*b*) *Checking the Ways and Fundamental Movements.* The flatness of the base plate should be tested by use of a spirit level about 10 in. long or by using a spirit level on a bridge piece, the feet of which should be 12 in. to 20 in. apart. The drilling table which is mounted on this base plate must also be subjected to this test. During the observations the arm and saddle must be in their middle positions.

The spirit level is placed in the positions shown at *a*, *b*, and *c*, Fig. 71, and then transversely in the positions *d*, *e* and *f*. The readings of the spirit level in these two directions at right angles indicate concavity or convexity of the base plate. A limited concavity is the only permissible deviation from the true plane.

A number of readings with the spirit level in the positions shown is essential, if a true image of the base plate is to be obtained. The use of a long straight-edge, on which to place the spirit level, is forbidden, as this obliterates the true form of the surface.

(*c*) *Checking the Relation of the Axes of Rotation to Other Important Units.* In the case of *radial drilling machines* it is necessary to make the following tests :

(1) Check the *parallelism* of the saddle ways with the base plate.
(2) Check the perpendicularity of the drilling spindle to the base plate, both longitudinally and transversely.
(3) Check the *perpendicularity* of the feed movements of the drilling spindle against the base.

(1) The arm must always remain parallel to the base plate as it turns round the column. This is checked by placing a spirit level on the front end of the arm, Fig. 72, and observing the indications of the level, as the saddle is moved along the entire radius. The level used should be graduated to read 0.0005 in./foot. As the

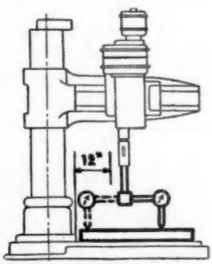


Fig. 76.—Perpendicularity of main spindle to the base plate.

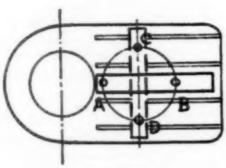


Fig. 77.—Straight-edge between indicator and base plate.

permissible error is 0.0025 in. per foot, the corresponding movement of the bubble for the above level will be five divisions. The only permissible inclination of the arm is downwards towards the outer end, because the drill thrust tends to raise the outer end.

With most designs the saddle is eccentrically guided on the vertical surface of the arm.

The flatness of this surface should be checked in a way similar to that used for the horizontal surface of a lathe bed, using a frame level at intervals of 8 in., Fig. 73. If the design includes a slit arm with a central guiding surface for the carriage on the underside of the arm, the foregoing procedure can be readily modified to suit this design.

An alternative method of checking the parallelism of the saddle ways with the base plate is to replace the spirit level by a dial gauge and straightedge as shown in Fig. 74. Set the arm in the middle position and place a straightedge 40 in. long along the longitudinal axis of the base plate. Fix the dial gauge in the drilling spindle and adjust the feeler so that it touches the straightedge. Move the carriage along the entire radius and observe the indications of the

dial gauge. It is not sufficient to check isolated parts of the movement. The error must not exceed 0.0025 in./foot.

A third procedure is to use the clock in the spindle in three different positions, *a*, *b*, *c*, of the swivelling arm and to check the parallelism of the base plate in swinging the clock indicator over the surface of the base plate ; tolerance 0.002 in. per foot (Fig. 75).

If the base plate is made in the form of T or a cross, the method of the swinging arm can easily be used.

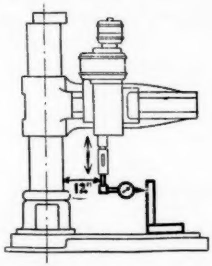


Fig. 78.—Perpendicularity of feed movement of spindle to table. (Lengthwise.)

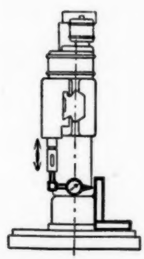


Fig. 79.—Perpendicularity of feed movement of spindle to table. (Crosswise.)

(2) (Fig. 76.) In order to check the perpendicularity of the drilling spindle to the base plate, set the arm to one-third of the height of the column and arrange the spindle so that it is 12 in. from the column flange. Place a straight-edge on the base plate and fix a dial gauge to an arm at least 10 in. long attached to the spindle. Turn the spindle through 360° and observe the indications of the dial gauge. Move the carriage outwards to two-thirds of its full radius and repeat the trammel reading. Adjust the height of the arm to two-thirds its maximum value and repeat the whole of the above procedure for this arm position. The only permissible error is an inclination of the lower end of the spindle towards the column. The straight-edge should be turned at right angles to its original direction and the above procedure repeated, Fig. 77.

The straight-edge can be eliminated and the feeler of the dial gauge set directly to the machine base. In this case a much larger and more representative range of observations can be made. Furthermore, it is possible to detect irregularities in the surface of the base plate.

(3) In order to check the perpendicularity of the feed movements of the drilling spindle against the base, set the arm in the middle position and the spindle 12 in. from the column. Attach a dial gauge to the spindle and adjust the feeler against the free arm of a square placed on the base plate. Move the spindle up and down

and observe the indications of the dial gauge. The only permissible error is an inclination of the lower end of the spindle towards the column. The above test must be performed with the square and dial gauge longitudinally on the base as shown in Fig. 78 and then transversely as shown in Fig. 79. Move the carriage to two-thirds the maximum radius and repeat the whole of the above procedure.

MAINTENANCE is the act of maintaining, sustenance, continuance. To maintain is to preserve, keep in state, continue.

Maintenance and repair are important and active functions of the productive side of a work's organisation. Their aim is to maintain the productive efficiency of the equipment, its continuance. They are best done actively, by anticipation, to prevent the delays which are inseparable when breakdown occurs.

The sanction to overhaul the machine and to examine the merits of such a procedure a sanction sheet should be made up with at least the following information taken from a British engine manufacturing works.*

MACHINE NO. ....

Date ....

JOB NO. ....

Machine Overhaul Sanction Form

Description of machine ....

Date purchased .... *Price* ....

Present book value .... *Present market value* ....

Cost of a new up-to-date machine of same type ....

A brief statement to denote the relative production value of a new machine of same type ....

Hours in use ....

Repairs for last two years cost ....

Repairs for current year cost ....

Last overhaul cost .... *Date* ....

Special reason for overhaul ....

Extent of overhaul proposed ....

Estimated cost ....

Remarks ....

Length of time machine can be released for overhaul ....

.... (obtained from progress department) ....

Overhaul sanctioned ....

Technical and economical factors must be balanced before the repair or even the rebuilding of a machine tool ought to be ordered.

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* c.f. Maintenance of Machine Tools by J. W. Mallett, *Journal of the Institution of Production Engineers*, March, 1938, p. 148.

WAR EMERGENCY COMMITTEE

Memorandum on The Efficient Utilisation of Labour Under War Conditions

AN outstanding difficulty with which all production executives are called upon to deal is that of obtaining an adequate supply of skilled mechanics to meet the requirements of munitions production programmes. Prior to the war it was known that the supply of skilled labour was inadequate to meet the reasonably balanced requirements of peace-time manufacturing programmes, whilst the outbreak of war, in which mechanisation has become a deciding factor, has created a demand for such labour out of all proportion to the normal requirements of industry. The change in the nature of product requirements with its concentrated and heavily increased demands for such items as aircraft, tanks, guns, shells, etc., has also completely upset the balance of types of skilled labour requirements.

Many men highly skilled in their normal sphere of operations are now totally unsuitable without further training and experience for use on specialized operations essential to the production of munitions. The change in product has also made many existing machine tools redundant, and a huge programme of machine tool manufacture has in consequence had to be undertaken, the production of which has absorbed a large amount of highly skilled labour.

Much of the existing stock of tools and equipment suitable for the manufacture of normal products has become a frozen asset due to its unsuitability for munitions production, whilst the change over to munitions has created a demand for jigs, tools, gauges, and equipment of a special nature which has had to be designed and manufactured in sufficient quantity to meet both production requirements and also to build up replacement stocks.

This programme has placed an almost overwhelming load on the tool and equipment manufacturing organizations throughout the country, and has vastly increased their demands for the highest grades of skilled labour.

The mechanization of the fighting forces has also created a demand for skilled mechanics for the purpose of repair and maintenance of its mechanical equipment, and as the supply of such equipment increases so will the demand for labour for its repair and maintenance increase. The problem, for which a solution has to be found,

is one of ever increasing demands for skilled engineering labour with a totally inadequate supply from which it can be drawn.

Past experience proves that skilled labour can only be produced by going through a long course of training and practical application, and it is obvious that the time factor precludes any possibility of obtaining, by the use of normal methods of recruitment and training, any increase of the higher grades of skilled labour of sufficient magnitude to meet present requirements.

The position may be regarded as analogous to that existing where the supply of a given high grade material is insufficient to meet production requirements. Analysis of such a problem with a view to finding a satisfactory solution would lead to an investigation to ensure that available material was being efficiently utilized and that it was only used for such purposes as demanded its particular virtues and qualities and whether substitute materials of a similar nature but of lower quality could not be utilized.

The use of such substitute materials would frequently entail fairly drastic changes in planning and structure of a nature which would not be regarded as economic or acceptable under normal conditions of material availabibility, but which would be agreed as justifiable as a temporary measure under prevailing circumstances of non-availability of material.

Material specifications and the duty which such materials were to perform would be analysed in much greater detail than under normal conditions. Structures and mechanisms which would normally be made completely from the higher grade materials would be made from composite materials, the higher grade being used only for those parts for which lower grade material was unsuitable.

The problem of shortage of skilled labour must be handled on similar lines to that of shortage of materials and every endeavour made to ensure that the skill of existing trained operators be utilized efficiently.

The same process of analysis in detail form must be applied to the tasks which skilled operators are called upon to perform and must be carried out to an extent which would not be considered economic or desirable if ample supplies of skilled labour were available.

The objective should be to make the task fit the type of labour available rather than wait until labour is trained to a standard suitable to handle the ordinarily accepted layout of operations.

It is agreed that, according to the normal standards of industrial requirement, labour is graded to deal with the allotted tasks in a most efficient manner, and it therefore follows that without further drastic analysis and breakdown of operations with a view to simplification of tasks, the distribution of existing skilled labour forces cannot be materially improved.

An important contribution to the problem of redistribution can,

of course, be made by promoting or upgrading of labour to perform tasks of a higher grade after a shorter period of experience than would normally be considered necessary.

This method does not, however, ensure the full and efficient utilization of the acquired skill of operators, neither does it assist directly in the absorption of the available mass of untrained labour which must be regarded as the raw material of the labour supply phase of industry. Nevertheless, such promotion and upgrading should be carried out to the fullest possible extent and can be regarded as a forcing ground for the production of labour capable of handling the higher grade skilled operations.

The grade of labour allocated to any particular operation in the engineering industry is determined by the degree of skill necessary to the performance of some particular portion of that operation. Keen analysis of such operations will more often than not reveal possibilities of segregating those portions requiring a high degree of skill in performance, the remaining portion being such as can be carried out by operators of a lower degree of skill. This applies to practically all operations in the manufacture of engineering products but applies with particular emphasis to machining operations. Since the shortage of skilled labour is particularly acute in that field it is vitally necessary to ensure, so far as is practicable, that operations are split in such a way that the tasks assigned to the higher grades of skilled labour are appropriate to their skill and training.

It may be argued that the double or triple handling of a piece due to the splitting of operations means an increase in the number of man hours taken to handle a given amount of product. In some cases this may be true, but it must be regarded as practicable to do so if a larger over-all output can be achieved owing to the absorption of additional labour of a lower degree of training and experience.

Experience has, however, proved that in many cases sub-division of operations has actually increased output from a given amount of plant and has also enabled lower grade machinery to be used with maximum efficiency.

Machinery of a low grade type unsuitable for finishing operations can be used for roughing and semi-finishing operations using much heavier feeds than would be practicable on machines which must be maintained in a suitable condition for carrying out precision finishing operations.

The sub-division of operations cannot be carried out successfully by haphazard methods, but must be subject to carefully planned analysis with a view to setting out the processes in a manner calculated to produce a series of graded tasks.

Efficient planning along these lines should produce task grading of the flow type by means of which it should be possible to absorb

inexperienced labour for the simpler tasks and by easy stages of progression to bring it along through the semi-skilled range until it is capable of carrying out the lower grade skilled tasks. This method of operation planning simplifies the problem of tuition of trainee labour, and the provision of instructors for the purpose of giving such training, as existing labour with the assistance of toolsetters, chargehands, and foremen will be found capable of coaching labour through the simple stages of progression.

Existing operators capable of setting up their own machines can be rapidly upgraded to the rank of toolsetters and the breakdown of operations into simpler elements will be found to be of great assistance in this direction, and progress will be more rapid than would be the case if set-ups of a more complicated nature had to be made.

The centralized grinding of all tools and cutters should be planned and will be found to be the most economical and satisfactory method of tool maintenance. The policy of production simplification should be applied to all phases of production and such things as the provision of dummy setting pieces for roughing and semi-finishing operations, when handling work of a repetition nature, will be found advantageous and of great assistance in the quick resetting of tools.

It is also good practice in the case of upgrading of tool setters to provide a sample finished work piece to assist them in reading component part drawings, and this will often avoid mistakes and scrap work.

The question of the provision of such aids to production simplification as special jigs, fixtures, tools, and gauges need not be stressed, but even in this connection the carefully planned sub-division of operations can be of assistance. A jig or fixture for complicated operation may be of a costly nature both in money and in man hours taken in its manufacture, but sub-division of the operation and the provision of simple jigs or fixtures to handle a section of the operation will, in the case of existing jigs, enable increased output to be obtained at a lower tool cost. In the case of new work it should simplify design and cheapen the manufacture of jigs and fixtures and at the same time enable labour of a lower grade to be used for the less important sections of the operation. It is, however, vital that due consideration be given to the provision of proper location and datum points when designing such a sequence of jigs, otherwise the desired final accuracy of the product may be affected and the principle of simplification unjustifiably blamed for the error.

The problems of production executives in applying the process of simplification of manufacture are infinitely variable, depending upon the type of product and the volume in which it is to be pro-

duced; it would therefore serve no useful purpose to give details of particular applications in any field of engineering production technique. It can, however, be stated that the same fundamental principles apply whatever the product and whatever the volume of product may be.

Planned and co-ordinated action with a view to simplification of complex operations, must inevitably simplify the problem of utilization and training of the abundant supply of untrained labour for the lower grade tasks. It should also enable the existing skilled labour to be redistributed to handle a largely increased volume of production as such labour would only be used to carry out tasks to which such skill is essential.

The production principles enunciated are in everyday use in all engineering works to a greater or lesser degree, and the only divergence from existing practice now suggested is that operation simplification shall be carried out to a degree far in excess of what is necessary under ordinary industrial conditions, and that the absorption and training of unskilled labour shall be accelerated. Sound commonsense, co-operation between labour and industry along the lines suggested, together with the training schemes of the Ministry of Labour, should go far to solving the labour problems of the country.